Georgian Geographical Journal 2023, Vol.3 (2)

A Brief Overview of Joint Research of Vakhushti Bagrationi Institute of Geography M. Nodia Institute of Geophysics, and Georgian Technical University, Institute of Hydrometeorology over the Past 10 Years

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Abstract

For many decades, the Vakhushti Bagrationi Institute of Geography, TSU, has had close scientific ties with the M. Nodia Institute of Geophysics, TSU, and the Institute of Hydrometeorology, GTU. Over the years, these institutes have conducted a large number of joint research projects in various areas in the fields of geography, geophysics, and hydrometeorology. This activity has not diminished in recent years. In particular, the following joint studies have been carried out over the past 10 years: The general and distinctive features of karst phenomena in the territory of Georgia have been studied. The distribution of hail by average maximum size in the territories of municipalities in the Kakheti region of Georgia was studied. A simulation of the distribution of hailstones by average maximum size in the territory of Kakheti (Georgia) was carried out using data on the freezing level in the atmosphere and radar measurements. Various bioclimatic characteristics of the village of Mukhuri and the Martvili Canyon (Western Georgia) were studied. The ionisation and microclimatic properties of the Tetra cave (Tskaltubo, Georgia) were studied. An assessment was made of the selective absorption of atmospheric aerosols from the coastal zone of the Black Sea in the spectral range of 0.52-0.80 μm, as well as other climatic parameters against the background of climate change. The influence of short-term geomagnetic activity on the variability of meteorological parameters in the mid-latitude region was studied. A structured data study was conducted to study wind variability to assess drought in Georgia. A drought assessment was also carried out based on the SPEI and SPI indices for this territory. A connection has been identified between the normalised vegetation difference index, precipitation, and drought indices in the conditions of Kakheti, and a correlation of drought indices for different climatic conditions has been established. Work has begun on the use of machine learning and big data for environmental monitoring. Sediments in reservoirs have been studied using field experiments; the spatiotemporal distribution, genesis, and transport of bottom sediments have been determined; issues of solving the problem of siltation in reservoirs for the development of hydropower and coastal protection are discussed; and methodological aspects of determining landscape hydrological resources are discussed. The change in the number and extent of glaciers in the Dolra River basin in 1911–1960–2014 (Caucasus Mountains, Georgia) was studied using old topographic maps and Landsat satellite images. Between 1960 and 2014, the changes in the Chalaati and Zopkhito glaciers in the Georgian Caucasus were studied. In the future, it is planned to further strengthen scientific ties between these institutes.

Keywords: geography, geophysics, meteorology, hydrology

Introduction

This year marks the ninetieth anniversary of the founding of the Vakhushti Bagrationi Institute of Geography (TSU) and the Mikheil Nodia Institute of Geophysics (TSU) and the fiftieth anniversary of the founding of the Institute of Hydrometeorology (GTU). The scientific activities of these institutes are widely known both in Georgia and abroad. Each of the institutes has its own specific scientific area. At the same time, to more effectively solve a number of scientific problems, the scientific potential of these organisations is often combined. In particular, such problems include environmental issues, climate change, and natural disasters.

For many decades, these institutes were part of the Geosciences Department of the Georgian Academy of Sciences. The academy's unified leadership was in charge of coordinating their scientific activities. As a result of reorganisation, since 2011, the institutes of geography and geophysics have been part of Tbilisi State University, and the Institute of Hydrometeorology is part of Georgian Technical University. Since 2014, the main scientific activities of all institutes have been carried out in accordance with state programme funding. This reorganisation did not affect the closeness of scientific

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contacts between these institutes. Moreover, in a number of areas, these contacts have even intensified (for example, research into the bioclimatic potential of Georgia for the development of resorts and tourism, the development and implementation of new methods for studying various natural phenomena, joint expeditionary work, etc.).).

Below is a brief overview of joint research between these institutions over the past ten years.

Methods and Materials

The results of studies presented in published works [1-22] were analysed.

Results

The territory of Georgia is rich in a variety of natural conditions that both contribute to the development of the human environment (minerals, bioclimate, resort and tourism resources, etc.) and negatively affect it (almost all types of natural disasters).

In particular, the general and distinctive features of karst phenomena in the territory of western Georgia have been studied [1]. This territory is rich in unique karst phenomena in which a single karst-hydrogeological system is fixed. In this region, the existing karst phenomena are characterised by common (they are directly connected with limestone masses) and distinguishing signs, which are caused by geological and geotectonic characteristics and the intensive development of processes determined by climatic conditions; the physical parameters of the distribution of precipitation in the specified territory have been established; places of intensive flows of underground filtration streams and the direction of their movement have been identified; and georadar locational sections have been constructed. Geophysical studies carried out on the limestone massif of Migaria have revealed the distribution area of both previously recorded and recently found caves; their identification, mapping, and cadaster have been carried out.

In [2, 3], the results of modelling the distribution of hailstones by mean max diameter (D) in the territory of Kakheti (Georgia) using data of the freezing level in the atmosphere and radar measurements of hail max sizes in clouds are presented. Maps of the distribution of hail by the average maximum diameter in the territory of Kakheti for individual months, from April to September, have been built. The vertical distribution of D in the indicated territory in the range of heights from 0.11 to 3.84 km was studied.

Various bioclimatic characteristics of the village of Mukhuri and the Martvili Canyon (Western Georgia) were studied [4,5]. Some new information about the village Mukhuri in Western Georgia's bioclimatic features (Tourism Climate Index and light ion content in the air) is shown. This information can help the area become a better health resort and tourist destination. It is shown that for the development of mass tourism, the months from March through November are favorable. Researchers measured the amount of light ions in the air near the Khobistskali River in the Shurubumu karstic cave and forest. The results showed that ionotherapy could be developed in the area that was suggested. It is noted that all months of the year are suitable for therapeutic and preventive tourism [4]. The data about air equivalent-effective temperature (EET) and content of light ions in air in the Martvili Canyon environments (Western Georgia) in [5] are represented. The average monthly values of EET for the daytime hours vary from 2.8° (category "Coldly," January) to 23.5° (category "Warmly," August). A comfortable thermal regime is observed during May, June, September, and October. The concentration of light ions in the air on the surface of the river and waterfall inside the canyon varies from 1410 to 2460 cm3, which is minimally above the standard necessary for the health of people.

The ionisation and microclimatic properties of the Tetra cave (Tskaltubo, Georgia) were studied [6, 7].

The cave "Tetra" is located in the northern part of the health resort Tskhaltubo [6]. Taking into account the microclimatic and ionising properties of the cave (the high concentration of light ions), at the beginning of the seventieth century, it was used for treating patients with the respiratory and cardiovascular systems. During the 2008 expedition, it was discovered that the special door into the cave was broken up. The tracks of the unsanctioned presence of people were revealed inside the cave. That is, the natural state of the cave was disrupted (sealing, air cleanliness, etc.). As a result, the unique bioclimatic and radiation properties of the cave were disrupted. Accordingly, the concentration of light ions was the same as that in strongly contaminated industrial cities. Urgent measures for the restoration of the natural therapeutic potential of the cave "Tetra" were proposed. Recently, the Agency of

Protected Areas of Georgia carried out several measures to restore the original state of the cave, which practically led to the restoration of its unique microclimatic and bioclimatic properties. In particular, the results of expeditionary work in 2018 showed that the restoration of the radioactive and ionising state of the cave occurred. Therefore, the cave "Tetra," as in the early years, will be possible to use for therapeutic purposes. The organisation of regular studies of the microclimatic, bioclimatic, and ionising properties of caves in Georgia is planned [6]. Research in 2021 confirmed that the restored cave retains its characteristic radioactive and ionising state. This shows that the use of the cave for medical, tourist, or other useful purposes will not harm its natural state [7].

One study looked at how atmospheric aerosols from the Black Sea coast are selectively absorbed in the 0.52-0.80 εm range. Other climate parameters were also examined in the context of climate change [8]. The optical properties of mixed (continental and marine origin) atmospheric aerosols in the coastal zone have been studied, particularly the absorbing function of the aerosols in the 0.52–0.80 micrometre spectral range. Over the years, more than 2,500 complex expeditions were carried out, during which, in 28 spectral regions, the spectral composition of direct solar radiation with the help of optical filters in a 0.341 to 1067 micrometre spectral range was measured. At the same time, the vertical distribution of water vapour in the atmosphere and the total amount of ozone were also measured. We found the empirical coefficients of the Angstrom formula by looking at the optical density at the beginning and end of the spectral range (where no absorption was seen). This helped us determine the aerosol absorption function at 8 points in this range.

An evaluation of the climate parameters of the Black Sea Coastline in the context of climate change was conducted [9].

To evaluate the climate change level of this region, the dynamics of climate parameter (temperature and precipitation) changes during a certain time period were accessed and analysed. The study is based on the observation data of the National Environmental Agency and weather stations operating, in the past or at present, on the Black Sea coast. The data on air temperature (1930–2010) and sum of precipitation (1957–2006) for weather stations Batumi (air temperature 1931–2010) and Poti (1930–2009) and statistical, climatologic, and graphical analysis of the treatment of many-year meteorological data were used for the study. In particular, according to the linear approximation trend of 80-year observational data, the average temperature in Batumi increased by 0.70 °C. Meanwhile, the average temperature in Poti increased by 0.30 °C. The maximum temperature in Batumi increased by 3.29 °C, and the minimal temperature also increased by 1.65 °C. The maximum temperature in Poti increased by 1.42 °C, and the minimal temperature also increased by 1.21 °C. According to the linear approximation trend of 50 years (1957–2006) of observation data, the annual precipitation in Batumi decreased from 2650 mm to 2550 mm, i.e., by 100 mm. Meanwhile, the annual sum of precipitation in Poti increased from 1700 mm to 2150 mm, i.e., precipitation increased by 450 mm.

Due to global climate change, natural hydrometeorological disasters occur more frequently and intensely, and the study and investigation of these events require the unification of all institutional resources to achieve progress in the set of goals and objectives essential for stable state development. Among the enormous number of published scientific papers, there are remarkable recent studies dealing with the abovementioned problem [10–15]. In the articles, various climatic parameters and dangerous phenomena have been discussed: wind, heavy rain, temperature, drought, atmospheric perturbations, etc. All parameters and events are studied using modern methods, program packages, and data. Especially important is the use of data from the Earth Observing Satellite mission.

Reference [10] addresses a space weather prediction problem. This paper looks into what might happen when strong magnetospheric storms occur and how they might change the way weather works in the atmosphere. The goal is to find a link between changes in the magnetosphere and changes in the weather. Georgia is prone to hydrometeorological hazards, so it is crucial to look into the physical processes that cause them. Meteorological effects resulting from fluctuations in solar wind are poorly represented in weather and climate models. A geomagnetic storm is a significant disturbance of Earth's magnetosphere, exchanging energy from solar wind into Earth's space environment. These storms result from solar wind variations that significantly change the currents, plasmas, and fields in Earth's magnetosphere. Geomagnetic indices measure geomagnetic activity occurring over short periods of time. They have been constructed to study the response of the Earth's ionosphere and magnetosphere to changes in solar activity. The correlation between geomagnetic storms and meteorological elements (temperature, precipitation, wind) was carried out for the Georgian region using meteorological observations, NASA's Solar Dynamics Observatory, and NOAA Space Weather Prediction Centre data. The results show that there is a dependence between meteorological parameters and geomagnetic disturbances.

A structured data study was conducted to study wind variability to assess drought in Georgia [11–13]. Drought is a frequent phenomenon in Georgia. The SPI and SPEI drought indices were calculated to analyse drought frequency and intensity in the territory of Georgia in the 1991–2020 period. The structured data of the hydrometeorological observation net were used to calculate the following statistical parameters: Pearson correlation, mean deviation, and absolute deviation, both for the entire period and for months. The programs R and R-instat are used to calculate and visualise these parameters. The correlation coefficient is in good agreement for all cases, and the absolute deviation shows data scattering, which should be related to the complex relief of Georgia as well as the heterogeneity of the data series. The study is important for climate change assessment and hydrometeorological disaster early warning systems and may be used in nature-based solutions [12–15].

Work has begun on the use of machine learning and big data for environmental monitoring. Artificial intelligence (AI) and machine learning (ML) are also key technologies in big data analysis. The analysis of big data combines traditional methods of statistical analysis with computational approaches. The significance of big data in climate-related studies is greatly recognised, and its techniques are widely used to observe and monitor changes on a global scale. Climate computing combines multidisciplinary research regarding climatic data and system sciences to efficiently capture and analyse climate-related big data as well as support socioenvironmental efforts. Understanding the natural environment is increasingly important to respond to the negative impacts of climate change and anthropogenic pressures on finite natural resources [16].

Sediments in reservoirs have been studied using field experiments; the spatiotemporal distribution, genesis, and transport of bottom sediments have been determined; issues of solving the problem of siltation in reservoirs for the development of hydropower and coastal protection are discussed; and methodological aspects of determining landscape hydrological resources are discussed. The change in the number and extent of glaciers in the Dolra River basin in 1911–1960–2014 (Caucasus Mountains, Georgia) was studied using old topographic maps and Landsat satellite images. Between 1960 and 2014, the changes in the Chalaati and Zopkhito glaciers in the Georgian Caucasus were studied [17–22].

The process of sediment accumulation in reservoirs stops after the silting prism is formed on the body of the equilibrium bed, by means of which the river can transport a full range of sediment downstream. Presently, there is no approved method for forecasting the parameters of the silting prism and the equilibrium bed. To study the process of silting prism formation and equilibrium channel forecasting, field experiments were carried out on small mountain rivers in Georgia. The methodology of the natural experiment implementation was created. For the analysis of the obtained results, the methods of mathematical statistics and differential calculus were applied. The experiments showed that the equilibrium bed is much higher than the initial position of the riverbed, posing a serious threat of catastrophic inundation in the event of a flood. It was found that the final result of reservoir silting is an accumulative terrace, where an equilibrium channel is produced. The length of the train is a function of the maximum flow discharge, the deposit of runoff, the diameter of the bottom sediment, and the initial inclination of the riverbed. The fractional distribution of the sediments into silting prisms is determined by the type of reservoir regulation and the intra-annual distribution of the fluvial sediments. The mechanism of riverside destruction by water flow is considered a random process that depends on both the flow rate and riverside stability. Vulnerability, the characteristic of the riverside, is taken as an indicator of this process with respect to such influence, and the famous model "load-stability" from the theory of reliability is used for its identification [17].

The genesis, transport, and accumulation of settled sediments in mountain rivers are random processes in time and space that are defined by the river flow rate (Q m3/sec), the height of the basin (I), the inclination of the river, and basin geology. Genesis and the volume of river sediment are functions of the climate, and in accordance with its cycles, they increase during the warming period and decrease as the temperature falls. The main natural factors for sediment formation are glaciers, erosion, landslides, and flax. Sediment transportation: The process of sediment transportation by flow represents many variable functions, which are mainly described by Chezy-Maning and Airy laws. Aside from the aforementioned laws, this process is also subject to the regularity of dependence between the maximal diameter of the sediment (dmax) and the speed of the river (V, m/sec) in the head race of a water reservoir. In some places, the river crosses an uplifted ridge, or "epirogenic threshold," and the submersible lowland. The river saws such a threshold to create the so-called "equilibrium balanced riverbed" of its respective characteristics. If the speed of the threshold uplift is greater than the speed of the riverbed cut, then a depression is created, in which the river permanently deposits sediments to create a riverbed with a corresponding inclination, the so-called equilibrium riverbed. Some rivers use a significant part of the sediments to compensate for stagnations caused by "flax dams" or alluvial fans of flax. In [18], it is shown that the result of such processes is the creation of the Chiori grove, accumulative plain terraces of Saglolo and Chrebalo in the basin of the river Rioni, the creation of the Tianeti plain upstream of the river Iori, and many more. A significant amount of sediment is spent on the formation of sanding prisms in water reservoirs. The river consumes one part of the remaining settled sediments to create a balanced riverbed in the submersible lowlands and to neutralise the effect of sea eustasy. The second part of sediments is spent on the formation of deltas, the permanent filling of coastal beaches, and the creation of accumulative formations in the sea. The mountain reservoir is in conflict with seacoast protection and the security of population and infrastructure at the head race. Hence, the genesis of settled sediments in the river, places of natural accumulation, and sediment granulometry should be taken into account when choosing a reservoir. The optimal places for the construction of water reservoir dams are epeirogenic thresholds since the dam is uplifted there, and thus, the operation period of the water reservoir is relatively longer.

Georgia, as a seaside mountain country, faces three opposing issues: hydropower development, coastal protection, and flooding risks for riparian settlements and infrastructure. Present climate change will even further strengthen the processes of beach abrasions. For the study of the silting prism formation process and the forecasting of the equilibrium channel, natural field experiments have been carried out on small mountain rivers. The experiment showed that for approximately one year, silting prisms on some rivers closely reached their limited size, and an equilibrium channel was formed. The silting prism in the tributaries forms the sediment train that extends to the boundary of the top water level in the river. The length of the train (L) is a function of the maximum flow discharge (QM), the deposit of runoff (R), the diameter of the bottom sediment (d), and the initial inclination of the riverbed (I). For the purpose of a harmonious resolution of all problems, eroded beaches should be periodically artificially filled by the river sediment accumulated in reservoirs. It is necessary to organise a system of quarries in reservoirs [19].

The aim of the paper [20] was to determine the quantity of water resources according to the landscapes in Georgia using multifactorial analysis. Assessment of the potential of water resources (hydroscopic resources) in landscapes requires multifactorial analysis. Their potential is determined by the quantity of influent and effluent waters during certain time periods. This study was mainly based on multiyear hydrological data from Georgia, covering 90 rivers. The series of observations included a time scale of 40–50 years and, in some cases, even 70 years. The study was based on cadastral data from 150 hydrological stations and posts. The authors investigated different and similar landscapes according to the total supply of water resources. The landscapes situated under more or less uniform physico-geographical conditions are similar in their total supply of water resources. Landscapes within the limits of one type or even subtype differ according to the supply of water resources, particularly water resources, which are maximal under these conditions. The accuracy of the results has been testified to by the circumstances. The authors obtained approximately the same total values for Georgia as determined by the calculations made by different scientists using different methods.

Article [21] presents the changes in the number and area of the Dolra River basin glaciers during the last century in connection with climate elements. The Dolra River basin is located on the southern slope of the Central Caucasus, in the territory of Zemo Svaneti, and joins the Enguri River basin, which in turn is the main centre of the contemporary glaciation in Georgia. During the study, we used the 1:42,000 scale topographic maps of the 19th century, which were drawn up during the first topographic survey by using the plane-table surveying method. Additionally, the authors used the catalogue of glaciers on the southern slope of the Caucasus, compiled on the basis of th-century m maps in 1911 by a well-known researcher of the Caucasus, K. Podozerskiy. To identify the area and number of glaciers in the 1960s of the 20th century, we used the work of R. Gobejishvili, the Georgian glaciologist of the 20th and 21st centuries, composed on the basis of 1:50,000 scale topographic maps of 1960. The data for 2014 were obtained from Landsat aerial images of the L8 OLI/TIRS (Operational Land Imager and Thermal Infrared Sensor) taken in August 2014. In the mentioned study, except for the old topographic maps and aerial images, the climate information was collected from Mestia weather stations (Mestia is the regional centre of Zemo Svaneti, where the only operating weather station is located at present). Along with the dynamics of glaciers, the course of air temperature and atmospheric precipitation has been identified in the 20th century and at the beginning of the 21st century.

Discussion

Georgia has unique natural resources to create comfortable living conditions for its population and guests. Therefore, it is necessary to continue further research on these resources for their wider use for the needs of society. At the same time, due to climate change, there is a noticeable increase in various types of natural disasters (floods, landslides, mudflows, melting glaciers, droughts, etc.). Therefore, comprehensive monitoring of natural disasters (observations, analysis, and forecasts) is necessary, which will make it possible to create long-term and early warning systems about their activation as well as to develop methods and recommendations for preventing or minimising the consequences of these disasters. To accomplish these tasks, it is necessary to combine the efforts of scientists of various profiles from scientific organisations in different directions. An example of such fruitful cooperation is the above overview of joint research between the three institutes over the past 10 years.

Conclusion

In recent years, much modern equipment and tools have appeared for environmental research, both ground-based and remote. New methods for analysing the results of experimental studies have also appeared. Particular attention is given to the importance of comprehensive studies of the human environment. Considering this in the future, it is planned to further strengthen scientific ties between these institutes.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

N. B. and N. V. conceived of the presented idea. N. G. and T. Ts. prepared relevant material for review. N. V. took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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